MULTI-SCALE ANALYSIS OF ELASTO-VISCOPLASTIC POLYCRYSTALS

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Polycrystalline materials, such as most metal alloys, are widely used in many industrial applications. When a polycrystalline metal is subjected to the finite deformations, the individual grains deform and rotate. The difference of the orientation distribution of the grains from a random distribution is referred as texture. A textured material typically exhibits a plastic anisotropy that has important consequences on its strength and formability.

The overall response of a polycrystalline system is usually obtained by averaging the responses of the individual crystals, which are assumed to undergo homogeneous deformations defined based on the same grain interaction assumption. In the Taylor hypothesis [1], each crystal is subjected to the macroscopic deformation identically, and the macroscopic fields are computed as a volume average of grain fields. Although the averaging scheme based on the Taylor assumption is widely used and gives reasonably good predictions of texture and stress-strain behavior in many cases, it does not predict the inhomogeneous fields within the grains, which play an essential role in phenomena such as recrystallization, grain growth and precipitation.

In the present work, the elasto-viscoplastic behavior, interactions between grains, and the texture evolution in polycrystalline materials under finite strains are modeled using a multi-scale analysis procedure within a finite element framework. The complicated real polycrystal, an aggregate of crystals, is replaced by a material representative volume element (RVE) consisting of a small number of crystals, and a periodic distribution of such unit cells is considered to describe material behavior locally on the macro-scale. The elastic behavior is defined by a hyperelastic potential and the viscoplastic response is modeled by a simple power law complemented by a work hardening equation [2]. For a prescribed deformation path, the stress response and hardness evolution are obtained by integrating the constitutive equations by a fully implicit two-level backward Euler integration scheme together with a modified Lagrange variational principle to enforce the plastic incompressibility at the material scale. The finite element framework is based on a Lagrangian formulation, where a kinematic split of the deformation gradient into volume preserving and volumetric parts together with a three-field form of the Hu-Washizu variational principle is adopted to create a stable finite element method. Furthermore, the consistent linearization of a system of nonlinear equations is derived.

An example involving an aluminum alloy, the macroscopic effective stress-strain curve and texture evolution are compared to those from a Taylor model. Moreover, we analyzed plane strain compression and plane strain simple shear loading of a unit cell to predict non-homogeneous periodic micro-fields.

References
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